Classification of additive manufacturing processes

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Learn about the main categories of additive manufacturing along with a detailed explanation of each of the 3D printing methods that currently exist in industry.

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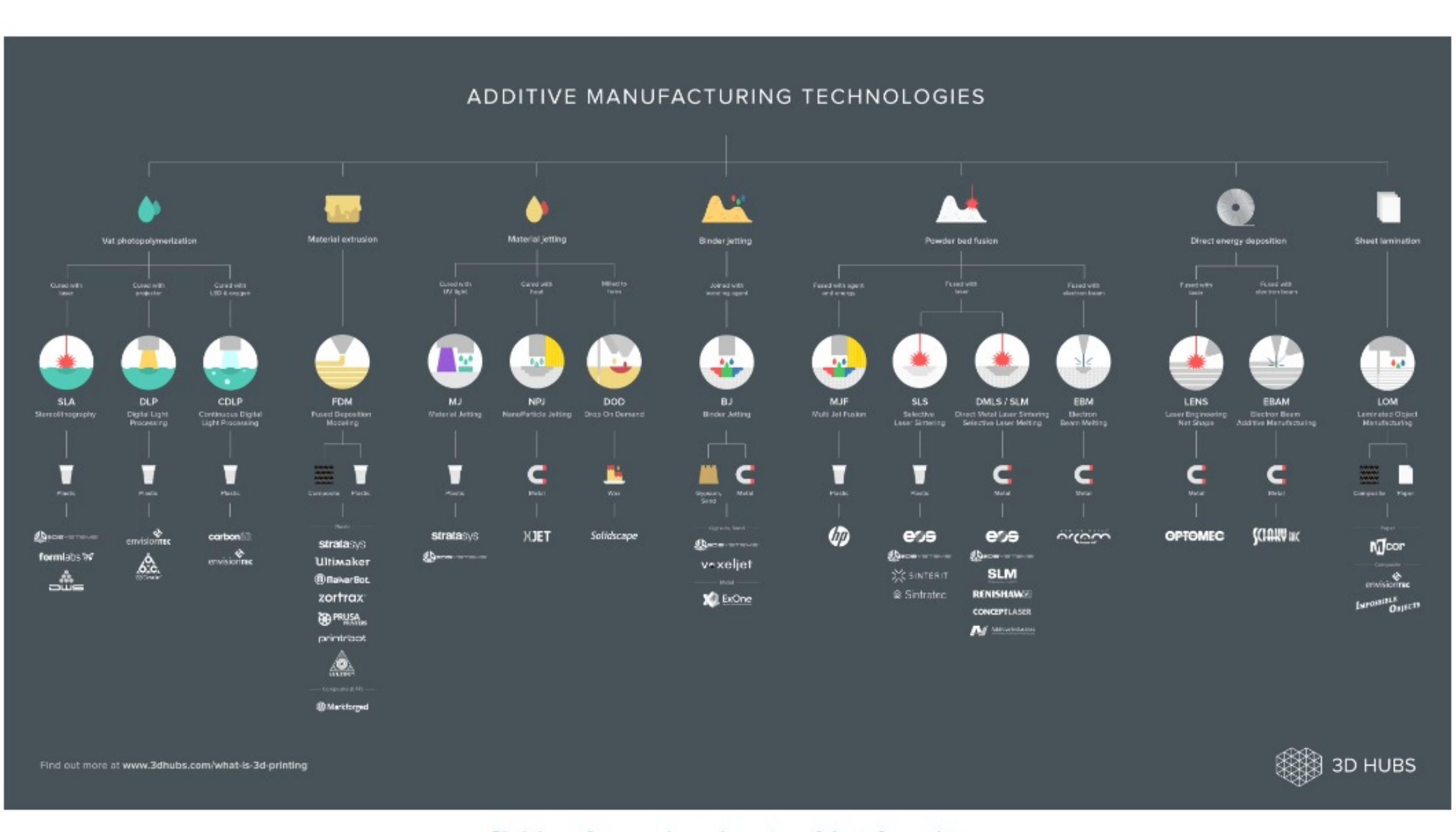
Introduction

Selecting the optimal additive manufacturing process for a particular design can often be difficult. The vast range of 3D printing methods and materials mean that often several processes are suitable but each offer variations in dimensional accuracy, surface finish or post processing requirements.

The goal of this article is to categorise and explain the difference between each of the additive manufacturing technologies. The most common printing methods will be identified along with the most common applications and materials that relate to each of them.



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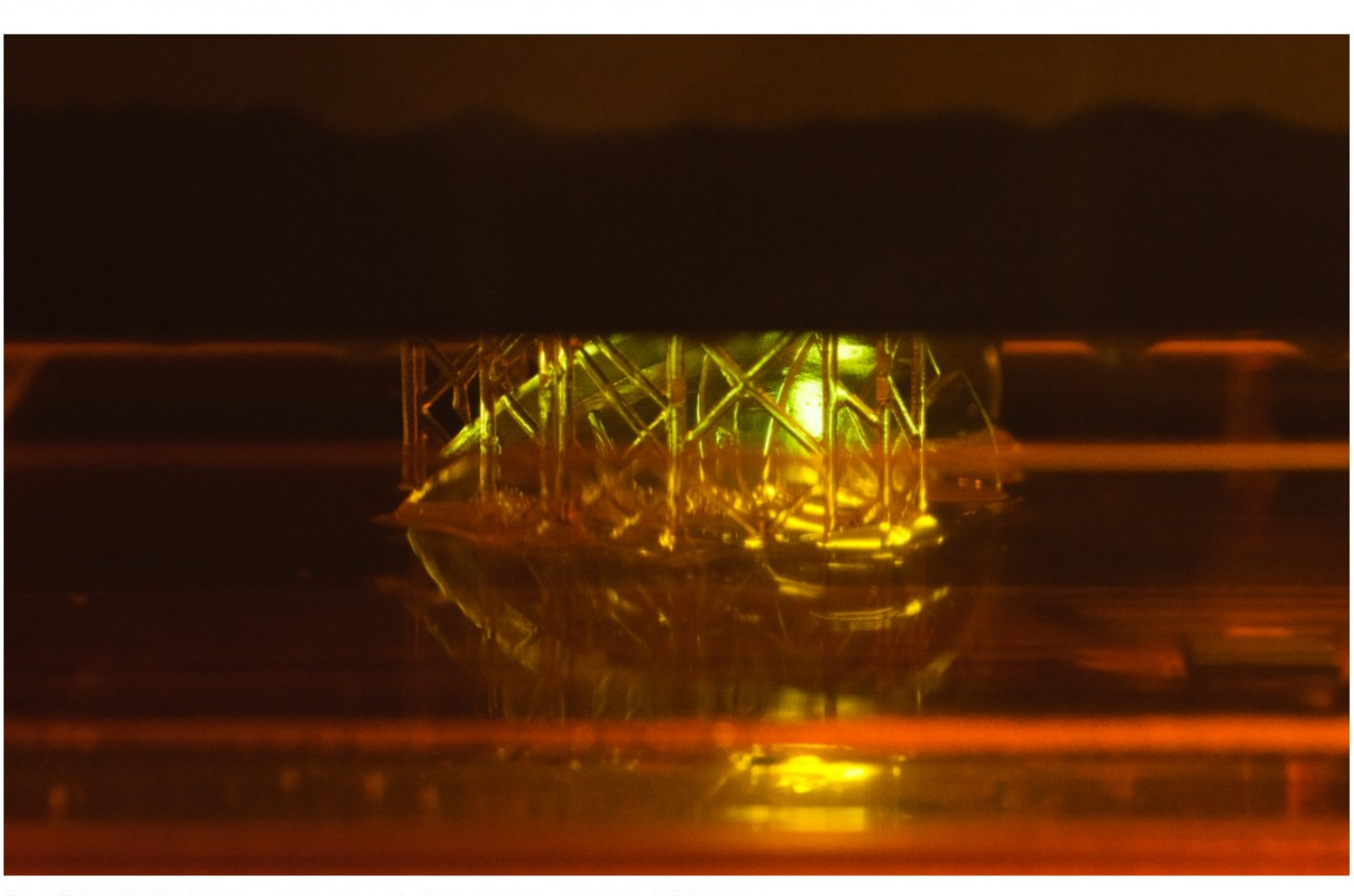
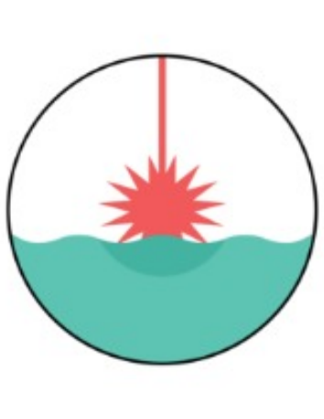
Vat photopolymerization

Photopolymerization occurs when a photopolymer resin is exposed to light of a specific wavelength and undergoes a chemical reaction to become solid. A number of additive technologies utilize this phenomena to build up a solid part one layer at a time.

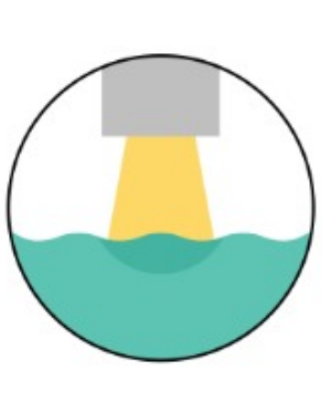


Some SLA methods of printing print parts upside down as they are drawn out of the resin

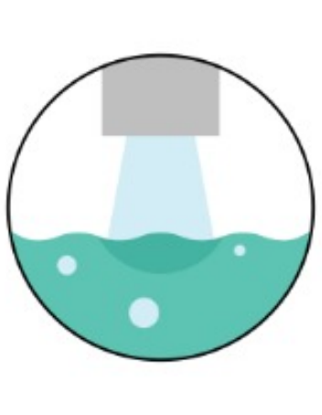
Technologies



SLA
Stereolithography (SLA) uses a build platform submerged into a translucent tank filled with liquid photopolymer resin. Once the build platform is submerged, a single point laser located inside the machine maps a cross sectional area (layer) of a design through the bottom of the tank solidifying the material. After the layer has been mapped and solidified by the laser, the platform lifts up and lets a new layer of resin flow beneath the part. This process is repeated layer by layer to produce a solid part. Parts are typically then cured by UV to improve mechanical properties. A full guide on designing parts for SLA printing can be found here.



DLP
Direct light processing (DLP) follows a near identical method of producing parts when compared to SLA. The main difference is that DLP uses a digital light projector screen to flash a single image of each layer all at once. Because the projector is a digital screen, the image of each layer is composed of square pixels, resulting in a layer formed from small rectangular bricks called voxels. DLP can achieve faster print times compared to SLA for some parts, as each entire layer is exposed all at once, rather than tracing the cross sectional area with a laser.



CDLP
Continuous direct light processing (CDLP) (sometimes referred to as continuous liquid interface production or CLIP) produces parts in exactly the same way as DLP however it relies on continuous motion of the build plate in the Z direction (upwards). This allows for faster build times as the printer is not required to stop and separate the part from the build plate after each layer is produced.

Applications

Vat polymerisation processes are excellent at producing parts with fine details and gives a smooth surface finish. This makes them ideal for jewelry, investment casting and many dental and medical applications. Material developments have also allowed the printing of low run injection molds. The main limitations for vat polymerisation are the build size and part strength.

Technology	Common manufacturers	Materials
SLA	Formlabs, 3D Systems, DWS	Standard, tough, flexible, transparent, & castable resins
DLP	B9 Creator, MoonRay	Standard & castable resins
CDLP	Carbon3D, EnvisionTEC	Standard, tough, flexible, transparent, & castable resins

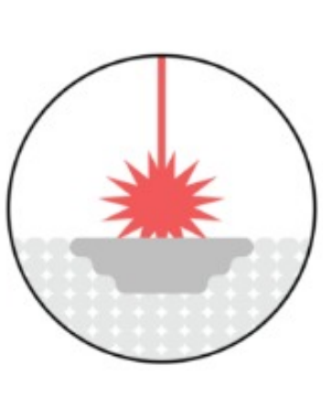
Powder bed fusion

Powder bed fusion (PBF) technologies utilize a thermal source to induce fusion between powder particles to a prescribed region of a build area, one layer at a time, to produce a solid part. Most PBF technologies employ mechanisms for adding and smoothing powder as a part is constructed resulting in the final component being encased in powder. The main variations in PBF technologies come from the differing energy sources (lasers or electron beams) and the powders used in the process (plastics or metals).

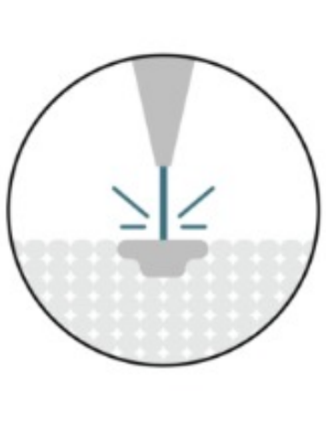
Removal of the powder pin from the SLS process with the printed parts still encased in unsintered powder

Technologies

SLS
Selective Laser Sintering (SLS) uses a laser to sinter thin layers of powdered material one layer at a time to create a solid structure. The process begins by spreading an initial layer of powder over a build platform. The cross section of the part is then sintered by the laser (solidifying it) at which point the build platform drops down one layer thickness. A fresh layer of powder is applied and the process is repeated until a solid part is produced. The result of this process is a component completely encase in unsintered powder. The part is removed from the powder and then cleaned (typically with pressurized air). In industry, SLS generally refers to the sintering process used to produce nylon (sometimes also ceramic) parts from powder.



SLM/DMLS
Both selective laser melting (SLM) and direct metal laser sintering (DMLS) produce parts via the same method as SLS. The main difference is that SLM and DMLS are used in the production of metal parts. SLM achieves a full melt of the powder while DMLS sinters the powders. This means that DMLS only works with alloys (nickelalloy, Ti64 etc.) while SLM can use single component metals such as aluminium. Unlike SLS, SLM and DMLS also require support to be included to compensate for the high residual stresses generated during the build process, helping to limit the likelihood of distortion occurring. DMLS is the most well established metal AM process with the largest installed base.



EBM
In contrast to other PBF technologies, electron beam melting (EBM) uses a high energy beam rather than a laser to induce fusion between metal powder particles. A focused electron beam scans across a thin layer of powder causing localised melting and solidification over a specific cross sectional area. These layers are built up to create a solid part. Electron beam systems produce less residual stress in parts, resulting in less distortion and less need for anchors and support structures. While EBM uses less energy and can produce layers at a faster rate than SLS, minimum feature size, powder particle size, layer thickness and surface finish are typically larger. EBM parts are also produced in a vacuum and the process can only be used with conductive materials.

Multi jet fusion
Multi jet fusion (MJF) works in a similar method to other PBF technologies with one extra step added to the process; a detailing agent. A layer of build powder is first applied to a work area. A fusing agent is then selectively applied where the particles are to be fused together followed by a localised detailing agent that is administered where the fusing action needs to be reduced or amplified. The detailing agent reduces fusing at the boundary of the parts to produce features with sharp and smooth edges. The work area is then exposed to fusing energy to solidify the powder particles. The process is then repeated layer by layer until a complete part has been formed.

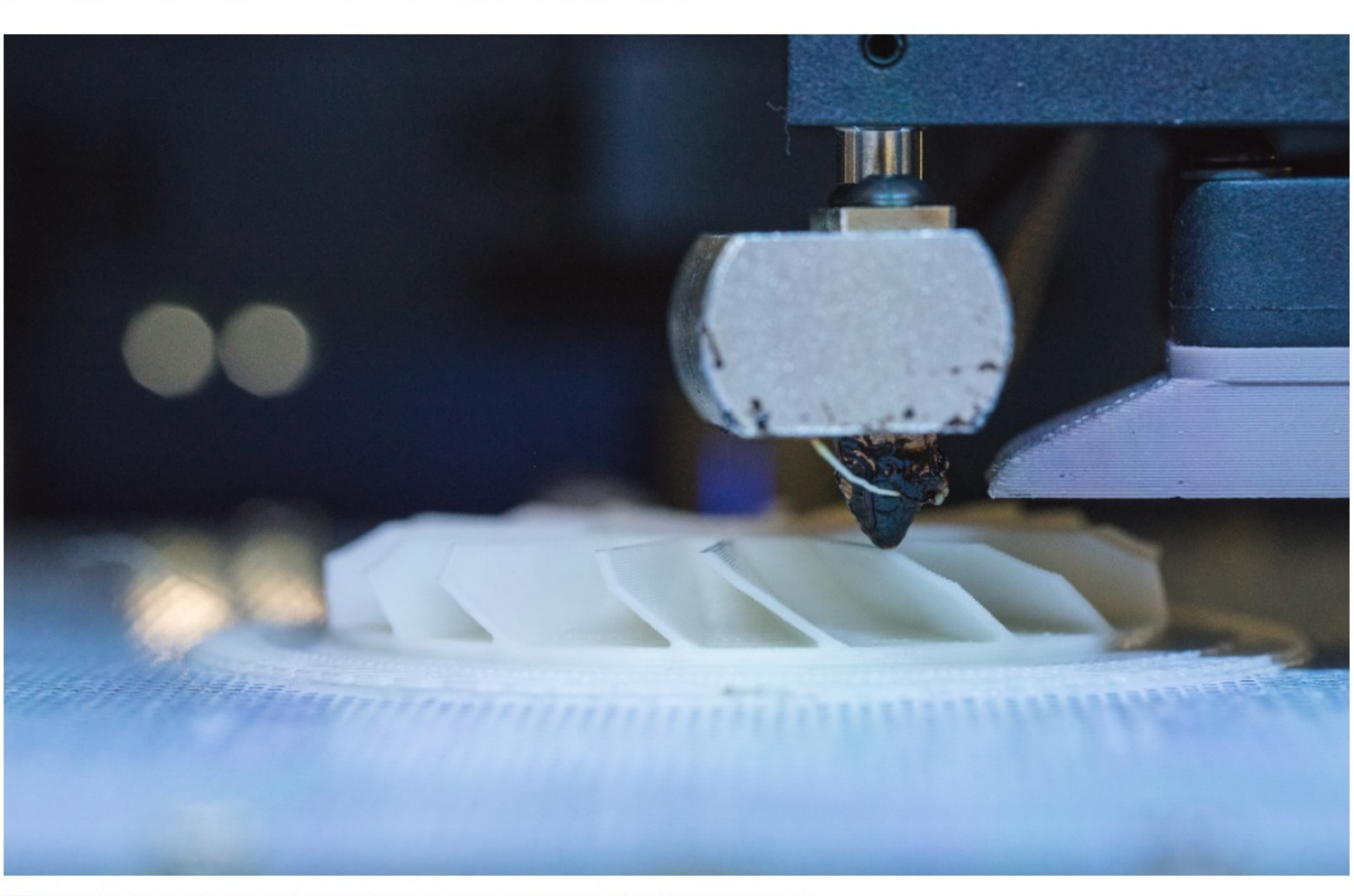
Applications

PBF technologies offer a lot of design freedom (typically no need for support) allowing for complex geometries to easily be built. Parts typically possess high strength and stiffness with a large range of post processing methods available meaning that often PBF is used to manufacture end parts. The limitations of PBF often center around surface finish (surface porosity and roughness), part shrinkage or distortion and the challenges associated with powder handling and disposal.

Technology	Common manufacturers	Materials
SLS	EOS, Stratasys	Nylon, alumide, carbon fibre-filled nylon, PEEK, PrimePart (flexible) nylon
SLM/DMLS	EOD, 3D Systems, Sinterit	Aluminium, titanium, stainless steel, nickel alloys, cobalt-chrome
EBM	Arcam	Titanium, cobalt-chrome
Multi jet fusion	HP	Nylon

Material extrusion

Similar to how toothpaste is squeezed out of a tube, material extrusion technologies extrude a material through a nozzle onto a build plate. A predetermined path is followed building a part up layer by layer.



FDM extrudes thermoplastic out of a heated nozzle over a predetermined path to build up parts

Technologies

FDM
Fused Deposition Modeling (FDM) (sometime also referred to as fused filament fabrication or FFF) uses a string of solid thermoplastic material (filament), pushing it through a heated nozzle and melting it in the process. The printer continuously moves this nozzle around, laying down the melted material at a precise location, where it instantly cools down and solidifies. This builds up a part layer by layer. FDM is the most widely used 3D printing technology. A full guide on designing parts for FDM printing can be found here.

Applications

Quick and cost effective method for producing non-functional prototypes. FDM has some dimensional accuracy limitations and is very anisotropic.

Technology	Common manufacturers	Materials
FDM	Stratasys, Ultimaker, MakerBot, Markforged	ABS, PLA, nylon, PC, fire-reinforced nylon, Onyx, exotic filament (bamboo-filled, wood-filled, copper-filled etc.)

Material jetting

Material jetting is often compared to the 2D ink jetting process. Utilizing photopolymers, metals or wax that cure or harden when exposed to light or elevated temperatures parts are built up (printed) one layer at a time. The nature of the material jetting process allows for different materials to be printed in the same part. This is often utilised by printing support from a different material during the build phase.

A material jetting printer illustrating how big the machines often are

Technologies

Material jetting
Material jetting dispenses a photopolymer from hundreds of tiny jets in a printhead to build up a part layer by layer. This allows material jetting operations to deposit build material in a rapid, line wise fashion compared to other point-wise deposition technologies that follow a path to complete the cross sectional area of a layer. As the droplets are deposited to the build platform they are cured by UV light. Material jetting processes require support and this is often printed simultaneously during the build from a dissolvable material that is easily removed during post processing.

Nano particle jetting
Nano particle jetting (NPJ) uses a liquid, which contains metal nanoparticles or support nanoparticles, loaded into the printer as a cartridge and jetted onto the build tray in extremely thin layers of droplets. High temperatures inside the build envelope cause the liquid to evaporate leaving behind metal parts.

DOD
Drop on demand (DOD) material jetting printers have 2 print jets; one to deposit the build materials (typically a wax-like material) and another for dissolvable support material. Similar to traditional AM techniques DOD printers follow a set path and jet material (in a point wise fashion) to generate the cross sectional area of a component layer by layer. These machines also employ a fly-cutter that skims the build area after each layer is produced to ensure a perfectly flat surface before printing the next layer. DOD technology is typically used to produce "wax-like" patterns for lost-wax casting/investment casting and mold making applications.

Applications

Material jetting is ideal for realistic prototypes, providing excellent details, high accuracy and smooth surface finish. Material jetting allows a designer to print a design in multiple colors and a number of materials in a single print. The main drawbacks to printing with material jetting technologies are the high cost and the UV activated photopolymers lose mechanical properties over time.

Technology	Common manufacturers	Materials
Material jetting	Stratasys (Polyjet), 3D Systems (MultiJet)	Rigid, transparent, multi-color, rubber-like, ABS-like & heat resistant resins. Multi-material, multi color printing in a single part available
NPJ	Xjet	Stainless steel, ceramics
DOD	Solidscape	Wax

Binder jetting

Binder jetting is the process of printing a binding agent onto a powder bed to form part cross sections one layer at a time. These layers bind to one another to form a solid part.

A binder jetting part after removal from the print powder

Technologies

Binder jetting
Binder jetting prints in a similar fashion to SLS where an initial layer of powder is required. The print head moves over the print surface depositing binder droplets (typically 80 microns in diameter) to produce a cross sectional area (layer) that forms the part. Once a layer has been printed the powder bed is lowered and a new layer of powder is spread over the recently printed layer. This process is repeated until a solid part is generated. The part is then left in the powder to cure and gain strength. After this the part is removed from the powder bed and the unbound powder removed via pressurized air. Sometimes an infiltrant is also added to improve mechanical properties. One of the main advantages of binder jetting is that nozzles can contain color allowing printing of complex geometries with lots of color.

Applications

Binder jetting is ideally suited for applications that showcase aesthetics and form (architectural models, packaging, ergonomic verification etc.) It is generally is not suited for functional applications where loads will be applied due to the brittle nature of the binder/glue connection.

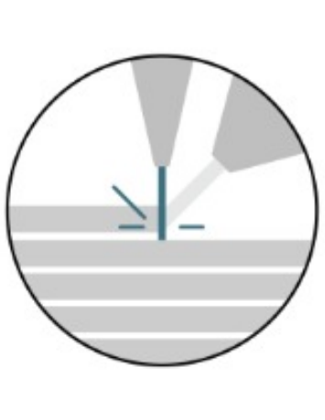
Technology	Common manufacturers	Materials
Binder jetting	3D Systems, Voxeljet	Silica sand, PMMA particle material, gypsum
Binder jetting	ExOne	Stainless steel, ceramics, cobalt-chrome, tungsten-carbide

Direct energy deposition

Direct energy deposition (DED) creates parts by melting material as it is deposited. It is predominantly used with metal powders or wire and is often referred to as metal deposition.

Technologies

LENS
Laser engineered net shape (LENS) technology utilises a deposition head comprising of laser optics, powder nozzles and inert gas tubing to melt powder as it is deposited building up a solid part layer by layer. The substrate is typically a flat metal plate that the part is built up upon or an existing part that material is added to. The laser creates a molten pool on the build area and powder is sprayed into the pool, melting and then solidifying.



EBAM
Electron beam additive manufacture (EBAM) is used to create metal parts using metal powder or wire welded together using an electron beam as the heat source. Producing parts in a similar fashion to LENS, electron beams are more efficient than lasers and operate under a vacuum with the technology originally being designed for use in space.

Applications

DED technologies are used exclusively in metal additive manufacturing. The nature of the process means they are ideally suited for repairing or adding material to existing components (such as turbine blades). The reliance on dense support structures make DED not ideally suited for producing parts from scratch.

Technology	Common manufacturers	Materials
LENS	Optomec	Titanium, stainless steel, aluminium, copper, tool steel
EBAM	Sciaky Inc	Titanium, stainless steel, aluminium, copper nickel, 4340 steel

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